Published in Air Traffic Control Association (ATCA) 42nd Annual Conference Proceedings, September 1997.

Generic Metrics for Conflict Probe Tools Developed for Free Flight

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INTRODUCTION

Free Flight is defined as a safe and efficient operating capability in which operators have the freedom to choose their own route, speed, and altitude in real time. To accomplish this, the FAA has sponsored the development of several ground based systems, such as the Automated En Route Air Traffic Control (AERA) developed by MITRE/CAASD and the Center TRACON Automation System (CTAS) developed by NASA Ames Research Center. One of the core functions of these ground based systems is a conflict probing tool. The conflict probe will allow the controller to identify future conflicts of predicted aircraft trajectories and suggest the appropriate resolutions. These predicted trajectories may also represent routes input into the probe by the controller, but requested by the pilot. The conflict probe provides the controller with a strategic tool to iterate various "Free Flight" requests by the pilot until an acceptable solution is determined.

The various developers have created performance metrics for their particular conflict probe; however, the FAA has the need to define a generic set of metrics that can be applied to any conflict probing tool. This paper discusses one of the generic metrics under development, referred to as "sharpness".

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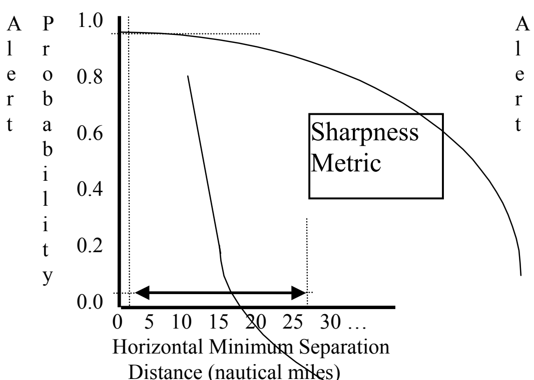
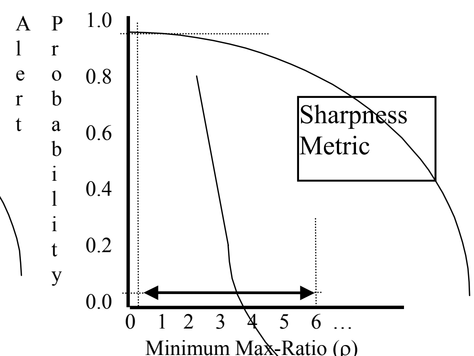
DEFINITION OF THE 'SHARPNESS' METRIC

The sharpness metric is a measure of the average sensitivity of a conflict probe's aircraft to aircraft conflict predictions[1]. To determine sharpness, a performance curve is formed by plotting the probability of a conflict prediction by the conflict probe versus the actual minimum separation distance between aircraft (refer to Figure 1a). The probability of a conflict prediction by the probe is the measure of the likelihood of an alert being presented to the controller for a particular aircraft pair. After both the aircraft complete their flights, the actual minimum separation distance is calculated from the Host Computer System's position reports. The sharpness metric is calculated by finding the intersection points of a probability close to 1 and the performance curve and a probability close to 0 and the curve. The distance along the x-axis between these two points defines the sharpness metric. Therefore, the sharpness metric indicates the precision of the conflict prediction by measuring the steepness of the performance curve. The steeper or more abrupt the incline of the curve, the better the aircraft conflict prediction.

One condition for the "perfect" conflict probe is the sharpness will equal 0. Its alert probability curve will not form a curve at all, but will be a step function. This perfect probe would have a probability of 1 in detecting a conflict with minimum separation distance of 0 up to the separation standard. At the separation standard and greater, the perfect probe would have a probability of 0 in detecting a conflict. The better the performance of the conflict probe under study, the smaller the sharpness distance will be.



(a) Sharpness for aircraft pairs on the same flight levels [4]



(b) Sharpness for all aircraft, captures both vertical and horizontal separation

Figure 1: Example of Alert Probability Versus Minimum Separation Distance

Considering only the aircraft pairs flying on the same flight level (i.e. with less than standard vertical separation), the area under the curve in Figure 1a is also a measure of the errors associated with the conflict probe. Since all conflict probe tools are detecting conflicts and making a prediction about the future, there are two basic errors that can take

[1] Sharpness expands upon the metric referred to as "crispness" in reference 4.

place. In statistics, these errors are often referred to as Type 1 and Type 2 errors. In the context of aircraft conflict predictions, the errors are referred to as missed alerts and false alerts. For a missed alert, the conflict probe does not detect a conflict, and for a false alert the conflict probe presents an alert that is not a conflict. In reference to the curve illustrated in Figure 1a , the area to the right of the standard horizontal separation is the joint probability of false alerts. The area to the left of this minimum separation is the joint probability of the correct prediction. By subtracting it from the probability of a conflict, the joint probability for missed alerts is determined.

To consider all aircraft pairs not just on the same flight levels, it is necessary to capture both dimensions of separation on the x-axis in Figure 1, since the legal separation of aircraft are presented in both the horizontal and vertical dimensions. For the horizontal dimension the standard separation is given in nautical miles, nominally 5 nautical miles. For the vertical dimension the standard separation is presented on a much smaller scale, nominally 2000 feet for aircraft above 29000 feet. In other words, an aircraft needs 15 times more separation in the horizontal plane than in the vertical. These two dimensions of separation distances are practically independent, but a conflict takes place only if both are violated simultaneously. Therefore, it is desirable to transform the separation in both dimensions into one value that corresponds to the aircraft pair's minimum separation.

A method has been developed to capture both independent processes. For the first step the separation distance in each dimension is normalized, so both values are on the same scale. This is accomplished by dividing the aircraft to aircraft separation by the standard separation for each time synchronized position report. The standard separations may vary depending on the location of the conflict (e.g. 1000 feet below 29000 feet and 2000 feet above). These ratios are expressed in the following set of equations.

The ratio of horizontal separation to standard horizontal separation can be expressed as:

$$\lambda_i = \frac{\left(\sqrt{\left(\left(x_i^a - x_i^b\right)^2 + \left(y_i^a - y_i^b\right)^2\right)}\right)}{\delta_i} \qquad \textbf{Equation 1}$$

where

δ_i = horizontal separation standard for the i th synchronized track data point;

x_i^a = x position of the i th track point of aircraft a in nautical miles;

x_i^b = x position of the i th track point of aircraft b in nautical miles;

and y_i^a , y_i^b are the corresponding y positions

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The ratio of vertical separation to standard vertical separation can be expressed as:

$$\pi_i = \frac{\left| z_i^a - z_i^b \right|}{\upsilon_i}$$ **Equation 2**

where

υ_i = vertical separation standard for the ith synchronized track data point;

z_i^a = altitude position of the ith track point of aircraft a in feet;

z_i^b = altitude position of the ith track point of aircraft b in feet.

Next, the maximum value of λ and π is calculated for each track point and the minimum from all these maximums is determined for each aircraft pair. The following equation expresses the calculation of the minimum of the maximum ratios.

$$\rho = \min_{i=1}^{k}\left[\max\left(\lambda_i,\ \pi_i\right)\right]$$ **Equation 3**

where

i = current ith track point ;

k = total number of track points.

The unitless distance, ρ, referred to as the minimum max-ratio of separation, combines both dimensions of separation and directly corresponds to standard separations. By definition, if ρ is less than 1, there exists a violation of standard separation, and if ρ is equal to or greater than 1 there cannot be a violation of standard separation.

The measure, ρ, is illustrated by the following example. Two aircraft were examined from Denver Center. This data was extracted from real data, so the standard horizontal separation was expanded to 10 nautical miles to demonstrate a conflict. Figure 2 plots the max-ratio of separation versus the flight time in seconds. Also plotted are the ratios λ and π, referred to earlier in Equation 1 and Equation 2. The dimension ratios illustrate the aircraft are steadily getting closer in the horizontal dimension, but increase separation in the vertical, reaching a separation 6 times the vertical standard. As these aircraft continue, the max-ratio does fall below the value 1 around a time of 1840 seconds. The conflict of less than 10 nautical miles continues for approximately 2 minutes until the vertical separation increases, then the max-ratio expands once again. The minimum of the max-ratio or ρ is approximately 0.8 around the time 1920 seconds of the flight. Since it is based on λ, it indicates that the minimum separation was around 8 nautical miles.

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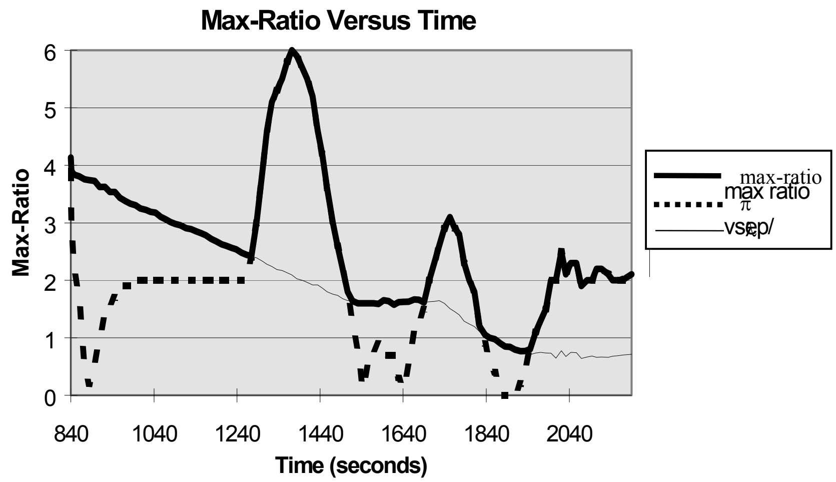

Figure 2: Example of Max-Ratio for Two Aircraft From Denver Center

CONCLUSION

The sharpness metric measures the precision of the conflict probe to predict a conflict. It will indicate the sensitivity a conflict probe has to the actual separation of the aircraft determined from Host track data. Similar metrics were used in the past to measure the sensitivity of the conflict detection for aircraft pairs only on the same flight level (refer to Figure 1a); however, by using the currently developed separation measure, referred to as the max-ratio, the sharpness metric can be expanded to capture all aircraft pairs in a given scenario (refer to Figure 1b). In the future, sharpness can be analyzed in relation to additional variables, such as conflict warning time.

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